Spectroscopic Binary Star Studies with the Palomar Testbed Interferometer II

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ABSTRACT

The Palomar Testbed Interferometer (PTI) is a long-baseline near-infrared interferometer located at Palomar Observatory. Following our previous work on resolving spectroscopic binary stars with PTI, we will present a number of new visual and physical orbit determinations derived from integrated reductions of PTI visibility and archival radial velocity data. The six systems for which we will present new orbit models are: 12 Boo (HD 123999), 75 Cnc (HD 78418), 47 And (HD 8374), HD 205539, BY Draconis (HDE 234677), and 3 Boo (HD 120064). All of these systems are double-lined binary systems (SB2), and integrated astrometric/radial velocity orbit modeling provides precise fundamental parameters (mass, luminosity) and system distance determinations comparable with Hipparcos precisions. More detailed information on our program can be found at http://huey.jpl.nasa.gov/palomar/binaries.

Table 1: System Properties

System	Spec Type	a (mas)	Mass Det (%)	π_{orb} (mas)	π_{HIP} (mas)
ι Peg	F5 V	10.3	1.2	86.9 ± 1.0	85.1 ± 0.7
64 Psc	F8 V	6.5	1.7	43.3 ± 0.5	41.8 ± 0.8
12 Boo	F9 IV	3.4	1.6	27.1 ± 0.4	27.3 ± 0.8
BY Dra	K6 V	*4.4*	*24*	*65.8 ± 5.4*	60.9 ± 0.9
75 Cnc	G5 IV	*5.9*	*4.6*	*31.4 ± 0.5*	32.0 ± 1.0
47 And	A1m	*5.1*	*6*	*16.1 ± 0.4*	15.4 ± 0.7
HD 205539	F0 IV	*2.1*	*9*	*13.4 ± 0.7*	13.9 ± 0.7
3 Boo	F6 IV	*3.8*	*9*	*11.1 ± 0.9*	12.0 ± 0.8

1. Introduction

PTI is a long-baseline near-infrared interferometer located at Palomar Observatory [Colavita 1999]. We have had an ongoing project to observe short-period binary stars; we have previously reported on results obtained in this program [Boden 1997, 1999a; Lane 1999; Boden 1999b, 2000a, 2000b].

Objectives of our binary star program is the determination of fundamental stellar (e.g. mass, luminosity, radius, rotation, evolutionary state) and system (physical orbit, distance) parameters for systems we study. We specialize in short-period systems because such systems are a match for our high-angular resolution observational niche, and offer the opportunity for accurate parameter determination and study of additional astrophysics (e.g. tidal interaction). Published examples of the high-precision determination of stellar and system parameters possible with PTI are given in [Boden 1999a, 1999b, 2000a].

Here we give descriptions of six new systems where we have completed our analysis or have solid provisional solutions: 12 Boo (HD 123999), 75 Cnc (HD 78418), 47 And (HD 8374), HD 205539, BY Draconis (HDE 234677), and 3 Boo (HD 120064).

2. Measurements and Analysis Methodology

The interferometric observable used for these measurements is the fringe *visibility* (squared) of a brightness distribution on the sky. Normalized in the interval [0:1], a uniform disk model for a single star exhibits visibility modulus given by:

$$V = \frac{2\ J_1(\pi B \theta / \lambda)}{\pi B \theta / \lambda} \tag{1}$$

where B is the projected baseline vector magnitude, θ is the angular diameter of the star, and λ is the observation wavelength. The expected squared visibility for a binary star is given by:

$$V_{nb}^2 = \frac{V_1^2 + V_2^2\ r^2 + 2\ V_1\ V_2\ r\ \cos(\frac{2\pi}{\lambda}\ \mathbf{B} \cdot \mathbf{s})}{(1+r)^2} \tag{2}$$

where V_1 and V_2 are visibility moduli for the two components (given by Eq. 1), r is the apparent brightness ratio, $\mathbf{B}$ is the projected baseline vector, and $\mathbf{s}$ is the primary-secondary angular separation vector on the plane of the sky.

Estimation of orbit models is made by fitting a Keplerian orbit model directly to the measured visibilities as predicted by Eq. 2. This is done both separately and in conjunction with radial velocity measurements [Boden 1999b, 2000a, 2000b].

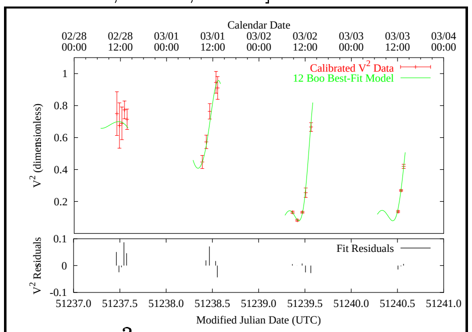

Fig. 1 V^2 Measurements and Best-Fit Model for 12 Boo (from [Boden 2000a]).

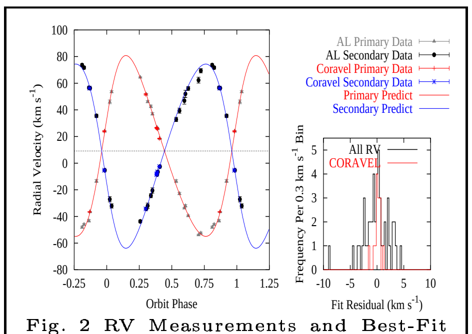

Fig. 2 RV Measurements and Best-Fit Model for 12 Boo (from [Boden 2000a]).

3. System Depictions

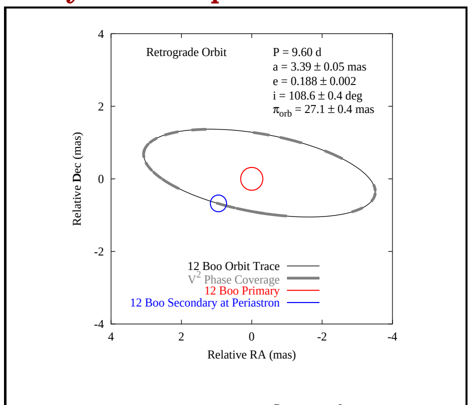

Fig. 3 Best-Fit Visual Orbit for 12 Boo (from [Boden 2000a]).

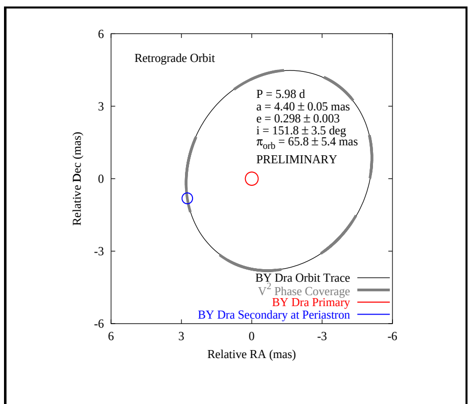

Fig. 4 Best-Fit Visual Orbit for BY Draconis (from [Boden 2000b]).

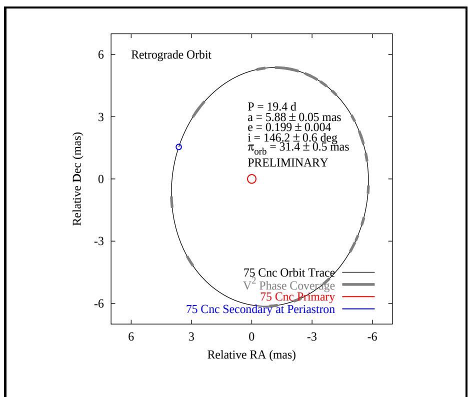

Fig. 5 Best-Fit Visual Orbit for 75 Cnc.

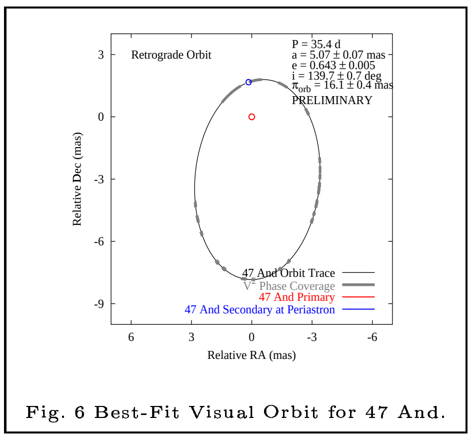

Fig. 6 Best-Fit Visual Orbit for 47 And.

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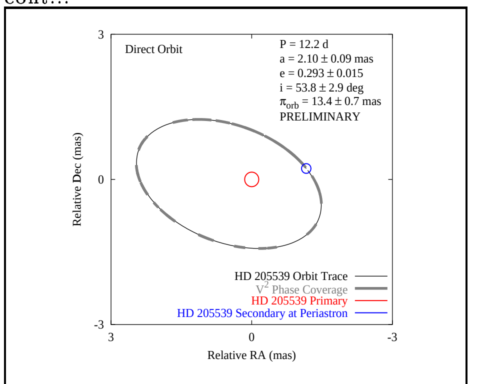

Fig. 7 Best-Fit Visual Orbit for HD 205539.

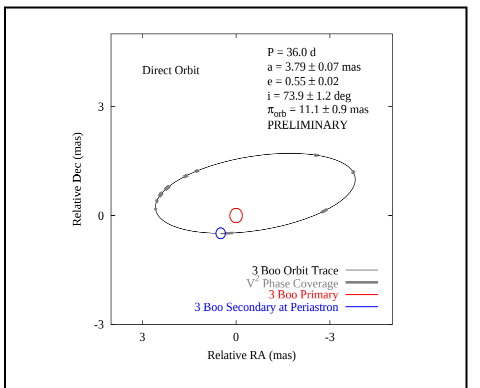

Fig. 8 Best-Fit Visual Orbit for 3 Boo.

4. Detailed Study: 12 Boo

Using the physical and visual orbit models we can straightforwardly compute physical parameters for the components of a binary system. We give an example of such an analysis on the system 12 Boo [Boden 2000a]; physical and orbital parameters are given in Table 2, and component physical parameters are given in Table 3.

Given the mass ratio near 1, we find a suprisingly large brightness difference between the two 12 Boo components. This fact motivates us to put the components on model stellar evolution tracks; this is depicted in Fig. 9, which gives the location of the two components in empirical mass-luminosity and color-luminosity diagrams. The brightness asymmetry is due to a unique phase of evolution of the 12 Boo components; we can date the age of the 12 Boo system at roughly 3 Gyrs. High-resolution spectra with ELODIE at Haute-Provance verifies the non-trivial intensity ratio in the visible, and indicates both components are at or near synchronous (not pseudo-synchronous) rotation with the orbital motion (see Boden 2000a).

Table 2: 12 Boo Orbit Parameters

Period (d)	9.604565 ± 1.0 × 10^{-5}
T_0 (MJD)	51237.779 ± 0.020
e	0.1884 ± 2.2 × 10^{-3}
K_1 (km s^{-1})	67.84 ± 0.31
K_2 (km s^{-1})	69.12 ± 0.48
γ (km s^{-1})	9.11 ± 0.13
ω_1 (deg)	287.03 ± 0.75
Ω_1 (deg)	10.17 ± 0.45
i (deg)	108.58 ± 0.36
a (mas)	3.392 ± 0.050
ΔK (mag)	0.618 ± 0.022
ΔH (mag)	0.566 ± 0.066

Table 3: 12 Boo Physical Parameters

Physical Parameter	Primary Component	Secondary Component
a (10^{-2} AU)	6.205 ± 0.032	6.322 ± 0.046
Mass (M_{sun})	1.435 ± 0.023	1.408 ± 0.020
Sp Type	F9 IVw	
Syst Dist (pc)	36.93 ± 0.56	
π_{orb} (mas)	27.08 ± 0.41	
Model Diam (mas)	*0.63* (± *0.06*)	*0.46* (± *0.05*)
M_{K-CIT} (mag)	1.200 ± 0.038	1.818 ± 0.039
M_{H-CIT} (mag)	1.269 ± 0.048	1.835 ± 0.063
M_V (mag)	2.524 ± 0.052	3.024 ± 0.077
V-K (mag)	1.324 ± 0.044	1.206 ± 0.072

12 Boo cont...

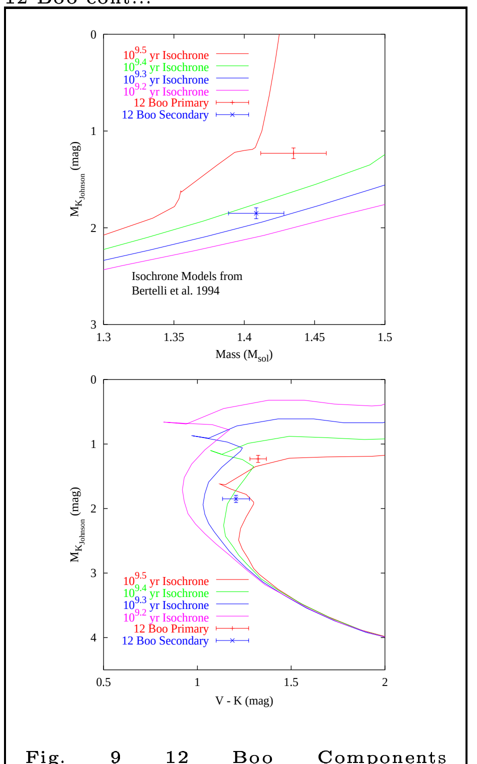

Fig. 9 12 Boo Components on Model Tracks (Models from Bertelli et al. 1994).

5. Discussion and Future Work

Several of the systems could profit from additional V^2 phase coverage, and we will obtain additional PTI data in the 2000 observing season. BY Dra is a special case because of its near-face on orbit geometry; because of its astrophysical inportance a significant amount of additional PTI data will be taken (Boden 2000b). However many of the systems suffer from a lack of modern RV study. Because of that we have initiated an RV program at Palomar and at Haute-Provance in collaboration with the Geneva Planet Search Program. Modern (tens-m s^{-1}) semi-amplitude determinations will yield mass estimates at or below the 1% level, and rotation measurements ($v \sin i$) to study tidal locking as we did for 12 Boo (Boden 2000a).

More detailed information and other results from our program can be found at http://huey.jpl.nasa.gov/palomar/binaries (see the laptop below).

References:

(Bertelli 1994) Bertelli et al. 1994, *A&AS* 106, 275.
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(Boden 2000a) Boden, Creech-Eakman, & Queloz 2000a, *Ap. J.* in press (astro-ph/9910245).
(Boden 2000b) Boden & Lane 2000b, *Ap. J. Lett.* submitted (astro-ph/0001138).
(Colavita 1999) Colavita et al. 1999, *Ap. J.* 510, 505.
(Lane 1999) Lane & Boden, Dana Pt Poster.